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FUNDAMENTALS OF BIOMASS PELLET PRODUCTION

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ABSTRACT: Pelletizing experiments and theoretical modeling of the pelletizing process have been carried out with the aim of understanding the fundamental physical-chemical mechanisms that control the quality and durability of biomass pellets. A small-scale California pellet mill (25 kg/h) is used to test the pelletizing performance of two wood species, the hardwood beech and the softwood pine. In accordance with experiences from large-scale pellets production, the test results show that the production of pellets from beech is significantly more troublesome than production of pellets from pine. Addition of 1 wt% calcium soap to the beech dust lowers the power consumption of the pellet mill. However, the calcium soap furthermore reduces the friction of the channels in the matrix, leading to lower durability of the produced pellets. It is proposed that the difference in pelletizing performance is a direct consequence of the difference in wood cell structure between hardwoods and softwoods, which in turn affects the mechanical properties of the biomass during pelletization. A novel model gives a theoretical basis for this finding.

Keywords: Pellets, biomass densification, biomass characteristics

1 INTRODUCTION

Biomass fuel pellets are densified biomass particles. Following densification the particles are transformed into an energy dense fuel of well-defined size. Pellets originating from different biomass sources are characterized by their durability, water content and ash properties. Softwood shavings and sawdust from wood manufactures have traditionally been the major source for fuel pellets, but the increasing demand for renewable fuels has introduced alternative biomasses such as hardwoods, straw and other bioresidues from agriculture and industry.

The introduction of different sources of biomass has made it clear that the pelletizing performance is highly dependent on the properties of the specific biomass, i.e. the dimensions of pellet mill have to be optimized to the biomass in question. This optimization is usually carried out on a trial and error basis, with the drawback that it has to be repeated for every biomass.

In order to avoid this time consuming step a fundamental knowledge of the physical-chemical mechanisms that control the pelletizing process is essential. Obviously, these mechanisms are dependent on the microscopic structure and chemical composition of the biomass, e.g. the macroscopic mechanical properties are controlled by mechanisms that are strongly influenced by the biomass structure at the cellular level. The present paper illustrates some of these points in terms of the strikingly different pelletizing performance of beech and pine, a hardwood and softwood with very different cellular structures. The results are given in a somewhat condensed form, whereas a more elaborate discussion is presented in [2].

2 EXPERIMENTAL SECTION

Densification of biomass can be performed with different equipment and is categorized accordingly: Piston press densification, screw press densification, roll press densification and pelletizing [1]. The first three types yield relatively large products usually known as briquettes. Pelletization using a ring matrix is the primary technique for producing large quantities of small pellets (see Fig. 1). The actual size of the pellets depends upon the dimensions of the channels in the matrix. Channel diameters of around 8 mm with a length of around 50 mm are common. However, as discussed later, the actual size has to be optimized for the specific biomass in question.

Figure 1: Disassembled California Pellet mill (25 kg/h) showing the ring matrix in the upper left corner. The roller is shown to the right.

A laboratory California pellet mill is shown in Fig. 1. The matrix has 40 channels with a diameter of 8 mm and a length of 50 mm. The eccentrically mounted roller shown to the right in Fig. 1 forces the biomass out through the channels. The friction between the biomass and the walls of the channels sets up a backpressure that is responsible for the compression of the biomass. The mill is equipped with an ammeter in order to monitor the motor current. The samples used in the present study are pine shavings and beech dust. Pine shavings are obtained as a commercial product whereas beech dust is obtained from a local wood floor producer (Junckers Industries A/S).

Table I: Particle size distributions of pine shavings and beech dust.

Particle size	*Dry Wt%*	
	Pine	Beech
> 5.60 mm	10.4	1.0
> 2.80 mm	29.9	6.6
> 1.00 mm	40.3	24.5
> 0.50 mm	13.0	24.0
> 0.25 mm	3.9	20.9
> 150 µm	1.3	10.2
> 75 µm	1.3	6.6
< 75 µm	0.0	6.1

Particle size distributions of the tested samples are shown in Table 1. A relatively larger proportion of small particles characterizes the beech dust, since it has been processed in a hammer mill. Before pelletization, the moisture content of the samples was adjusted to 12 wt%. The samples were at room temperature prior to feeding into the pellet mill. The beech dust sample containing 1 wt% calcium soap was mixed in a Björn Varimixer for 15 min.

3 RESULTS AND DISCUSSION

The pelletization of pine shavings did not cause any problems. The feeder rate could be maintained at a constant speed and the motor current was stable within a narrow range (Fig. 2). The pellets were characterized by high durability and low dust content (Fig. 3). Beech dust, however, did not perform well in the pellet mill. After a while when the beech dust had filled the channels, the motor current increased drastically and the feeder had to be turned off in order to avoid blockage (9min50sec in Fig. 2). Soon after the feeder was restarted, the motor current increased once more to a critical level and had to be turned off (11min20sec and 13min5sec in Fig. 2). Obviously, this is a highly unstable situation and at some point, the mill is likely to block (15min47sec). The pellets that were produced were durable and with a low dust content (Fig. 4).

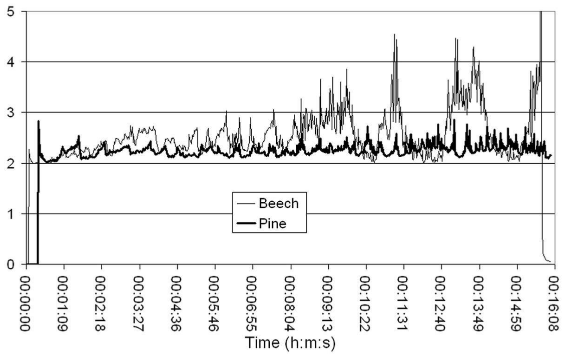

Figure 2: Time course of pellet mill current during pelletization of beech dust and pine shavings.

Figure 3: Pellets pressed from pine shavings.

Figure 4: Pellets pressed from beech dust.

As a possible additive to reduce the power consumption during pelletization of beech dust, 1 wt% calcium soap was mixed with the beech dust. As seen in Fig. 5, the effect on the power consumption was significant.

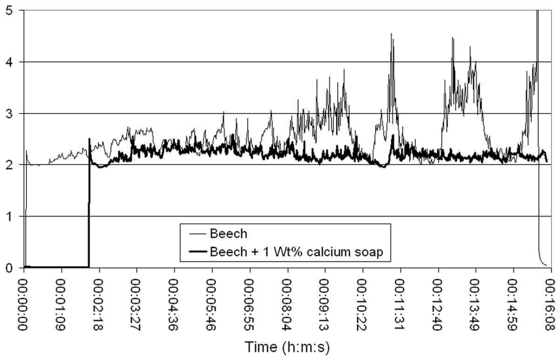

Figure 5: Time course of pellet mill current during pelletization of beech dust and beech dust + 1 wt% calcium soap.

However, the effect on the durability of the pellets was not favorable. The pellets were characterized by high dust content and a large part of the pellets showed swelling. This is likely to be a direct consequence of the reduced friction between the pellets and the channel walls, due to the lubricating effect of the calcium soap.

A novel theoretical model has been developed [2]. The model calculates the necessary pelletizing pressure, i.e. the pressure necessary to overcome the backpressure in the channels set up by the friction between the pellets and the channel walls.

Figure 6: Pellets of beech dust + 1 wt% calcium soap.

An elaborate discussion of the model can be found in [2] and will not be presented here. As one of the main results, the model predicts an exponential behavior of the pelletizing pressure as a function of channel length (Fig. 7). The model introduced parameters such as the matrix dimensions (channel length and radius), the sliding friction coefficient and the biomass specific elastic modules and Poisson's ratio.

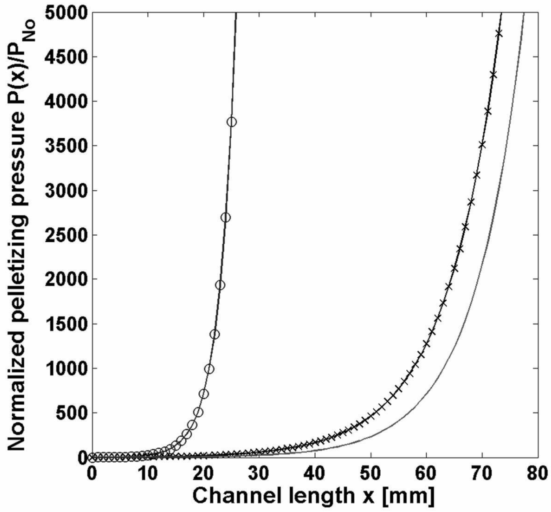

Figure 7: Simulation of the pelletizing pressure as a function of channel length of beech (circle), pine (cross) and beech + 1 wt% calcium soap (no markers).

Fig. 7 shows the calculated pelletizing pressure curves of beech, pine and beech + 1 wt% calcium soap. The pelletizing pressure is given normalized to a constant prestress P_{No} of the pellets in the matrix. Literature values of the elastic modules and Poisson's ratios for beech and pine are used [3, 4]. The sliding friction coefficient of beech and pine is set to 0.6. The effect of the calcium soap is simulated by reducing the friction coefficient of beech to 0.2. The radius of the channels is set to 4 mm.

Fig. 7 shows that the pelletizing pressure of beech increases more rapidly than the corresponding pressure of pine when the channel length is increased. If it is assumed that the pellet mill can deliver a normalized pelletizing pressure of 2000, pellets of beech can be produced up to a length of around 22 mm. Above this value the pellet mill is not able to overcome the backpressure, i.e. the mill will block if a matrix with longer channel length is used. In the case of pine, a normalized pelletizing pressure of 2000 would make it possible to produce pellets up to a length of approximately 64 mm, before the mill would block.

In the case where the addition of 1 wt% calcium soap is simulated by lowering the friction coefficient of beech from 0.6 to 0.2, the necessary pelletizing pressure is seen to decrease significantly. Now it should be possible to produce pellets up to a length of approximately 69 mm with a pelletizing pressure of 2000. It should be emphasized that the reduction of the friction coefficient from 0.6 to 0.2 due to the calcium soap is not based on any measurements, but freely chosen to illustrate the effect of lower friction.

If the actual matrix channel length is shorter than the length corresponding to the pellet mill's upper pelletizing pressure limit, the resulting backpressure will be reduced and may not even be high enough to compress the biomass sufficiently. This is likely to be the reason why the pellets with 1 wt% calcium soap have poor durability. The friction is evidently to low to produce the necessary backpressure.

One could speculate that the different particle size distributions of the beech and pine samples would influence on the pelletizing performance. This has not been tested in the present study, but large-scale pelletization experiments using the same hammer mill for comminuting both beech and pine lead to the same observations, i.e. beech was more difficult to pelletize than pine.

4 CONCLUSIONS

The present paper presents experimental pelletization results obtained with a laboratory-scale California pellet mill. By monitoring the power consumption of the pellet mill, it is shown that beech dust is more difficult to palletize than pine. Theoretical calculations using a model for the mechanical forces in play during the pelletization is in accordance with the experimental results. The model suggests that the difference in pelletizing performance is directly related to the fundamental mechanical properties of the biomass. Future work is aim at connecting these mechanical properties with the biomass structure at the cellular level.
Addition of 1 wt% calcium soap to the beech dust reduced the power consumption relative to the raw beech dust and no blockage was experienced. However, the durability was low and the pellets had a high dust content. The effect is suggested to be a consequence of reduced friction with the channel walls, in agreement with the theoretical simulations.

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